BBC RD 1992/1

Research Department Report

UHF TELEVISION RECEPTION:

Ghost images from very large buildings

D.T. Wright, C.Eng., M.I.E.E.
***and* D.R. Cornell**

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

BBC RD 1992/1

UHF TELEVISION RECEPTION: GHOST IMAGES FROM VERY LARGE BUILDINGS

D.T. Wright, C.Eng., M.I.E.E. and D.R. Cornell

Summary

This Report analyses the problem of ghost images to television picture reception caused by reflections from a very large building. For the particular case of the Canary Wharf Tower in London's Docklands, a basic theoretical analysis is compared with field measurements to gain some insight into the factors involved. Possible cures are also discussed.

Index terms: *UHF; reception; TV broadcasting; multipath propagation; interference; measurements; delay*

Issued under the Authority of

Ian Childs

Head of Research Department

Research Department, Engineering Division
BRITISH BROADCASTING CORPORATION

1992

UHF TELEVISION RECEPTION: GHOST IMAGES FROM VERY LARGE BUILDINGS

D.T. Wright, C.Eng., M.I.E.E. and D.R. Cornell

1. Introduction 1

2. Predicted Reflections in the Horizontal Plane 1

3. Field Measurements 2
   - 3.1 Measurement of affected area north of the tower 3
   - 3.2 Building reflectance 7
   - 3.3 Reflections in the vertical plane 7
   - 3.4 Southern reflection 8

4. Possible Cures for the Problem to the North 9
   - 4.1 Prevention at source 9
   - 4.2 Receiving antenna discrimination 9
   - 4.3 A new transmitter 10
   - 4.4 Cancellation at receiver 10

5. Conclusions 10

6. References 11

UHF TELEVISION RECEPTION: GHOST IMAGES FROM VERY LARGE BUILDINGS

D.T. Wright, C.Eng., M.I.E.E. and D.R. Cornell

1. INTRODUCTION

In some cases, satisfactory off-air reception of UHF television broadcast transmissions in cities can be difficult to achieve because of the presence of large buildings. It is also difficult to maintain because of the continual addition of new buildings and alterations to existing ones. The addition of a new building is likely to cause attenuation in its shadow with new and/or additional delayed image interference (ghosting) elsewhere. At the Canary Wharf development in London Docklands, the new and very large Canary Wharf tower has created reception problems over an extensive area; ghost images have been reported in previously unaffected residential areas well to the north of the city. An initial estimation, based upon complaints received, plus a brief survey, suggested that as many as 100,000 people may be affected by the ghost images. The problem for the 10,000 people living in the shadow of building developments, in general on the Isle of Dogs, had been dealt with by the installation of a relay station at Poplar; but the need to limit co-channel interference to other stations means that this relay must be kept to a power sufficient only for serving the immediate shadow area. It follows that the problem for the more extensive area affected by the ghost images cannot be alleviated by a conventional relay station.

The building creating the ghosting problem is a tower, 50 metres square and 242 metres tall, which was 'topped out' in November 1990. It has stainless steel cladding and metallised windows. Crystal Palace signals are being reflected from both the western and southern faces of this building. These reflections are at approximately 355 degrees EGN (East of Grid North) towards the Lea Valley and Walthamstow, and at approximately 175 degrees EGN through Greenwich and Catford. The effect of these reflections is the creation of a secondary 'ghost' image. The degradation of the picture quality varies from slight to severe depending upon the relative levels of direct and reflected signals. To the north, the ghost image is displaced on the television screen by a short distance (3 - 5% of picture width, to the right of the main image). The acuteness of these reflections was greatly increased when the stainless steel cladding was fitted to the sides of the structure. Reflections from structures comprising more 'conventional' materials, such as brick and concrete, are probably less than 5% whilst those from the Canary Wharf building may be as high as 80%.

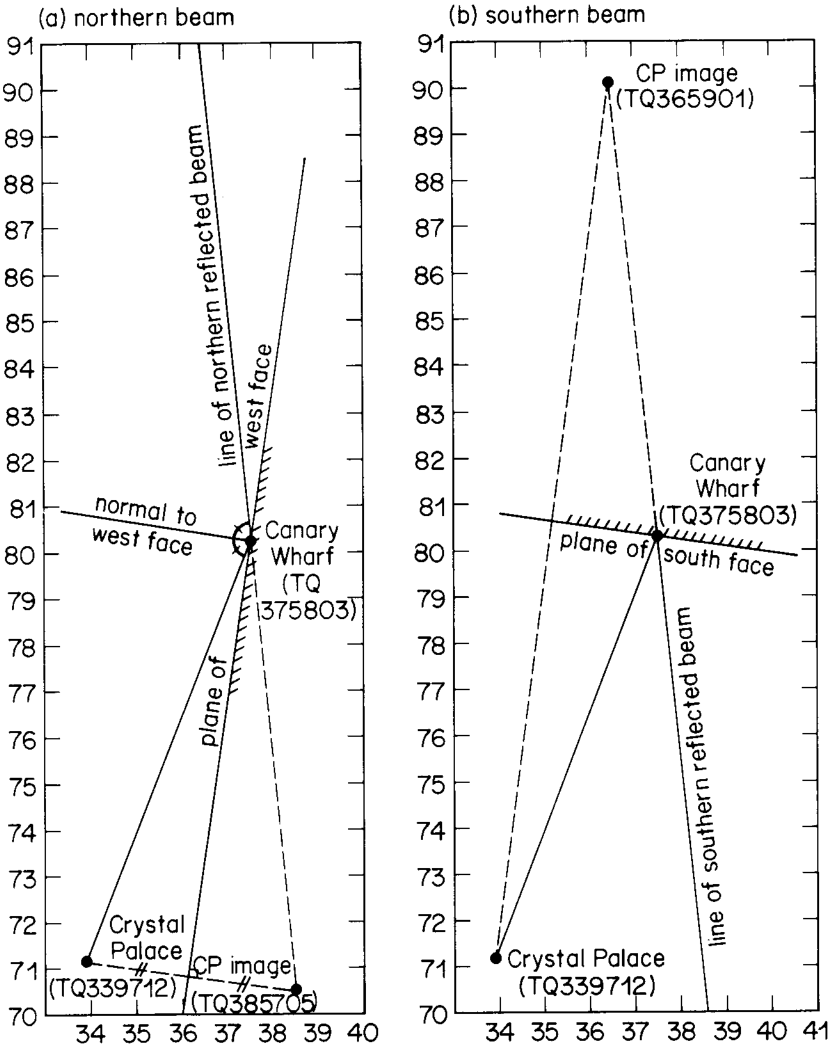
Of the two reflections, that towards Lea Valley and Walthamstow has the more severe effect on reception; this is largely because the direct signal and the reflected one arrive at the receiving antenna at such a small angle of separation (10 - 15 degrees), that a normal domestic antenna provides little or no discrimination between them. The second reflection, towards Greenwich and Catford, is less of a problem because the angle between direct and reflected signals is generally somewhat greater than 30 degrees and significant discrimination is readily achievable; although many people may still be affected due to shortcomings in their existing antenna installations. Two reported complaints to the south were found to be due to the use of an inadequate receiving antenna, whereas all those to the north were found to be justified.

2. PREDICTED REFLECTIONS IN THE HORIZONTAL PLANE

As a first approximation of the problem, use can be made of basic optics; treat the Canary Wharf tower as if constructed from four plane mirrors, and then make geometrical constructions to predict the width and directions of reflection beams to the north and south. Fig. 1(a) shows such a construction for the reflection off the nominal west face toward the north and Fig. 1(b) off the nominal south face toward the south.

For the northerly reflection, the bearing of the normal to the nominal west face is 278.43 degrees EGN; the incident signals from Crystal Palace approach on a bearing of 21.58 degrees EGN, so the angles of incidence and reflection are 76.85 degrees. As a result, the reflected signal will emerge on a bearing of 355.28 degrees EGN. The horizontal dimension of each face of the building is 50 m; therefore, with an angle of reflection of 76.85 degrees, the reflected signal beam will have a width at Canary Wharf of only 11.4 m. This beam appears to come from a point source at the position of the image of Crystal Palace at 9.8 km behind the tower to the south (National Grid Reference: TQ 385705).

For a perfect reflecting plane mirror, one would, on the basis of similar triangles, expect the beam width to be around 30 m at a point some 20 km north of the tower, and that, within this width, the ghost signal would be equal to the main signal. In practice, the face of the tower will not be a perfect



(a) Northern beam.

(b) Southern beam.

Fig. 1 - Direction of reflected beams by optical analysis methods.

reflector or be perfectly flat. There will be dispersion of the reflection beam, due to the non-flat surface and the presence of diffraction effects; the latter caused by the projected width of the mirror across the beam being less than 20 wavelengths at the frequencies under consideration.

In the southerly direction, a reflection off the nominal face of the building can be expected on a reciprocal bearing to the northerly beam, as in Fig. 1(b). In this case, the angles of incidence and reflection are 13.15 degrees, so the reflected beam will have a width at the tower of 48.7 m and will appear to come from a point source 9.8 km behind the tower to the north (TQ 365901). As the projected width of the mirror across the southern reflection is greater than for the north, any diffraction effects can be expected to be less on the southern reflection.

3. FIELD MEASUREMENTS

Subjective assessment of ghost images, using normal programme pictures, is likely to suffer wide variation, due to changes in the picture content and, to a lesser extent, due to changes of operator making the assessment. Therefore, it was decided to make objective measurements of the amplitude of the delayed image signal relative to the main signal; this was done by using the pulse and bar test signal on line 332 in the field interval[1]. It is generally accepted that the planning protection ratio for delayed image interference is 26 dB (5% relative signal amplitude) and that this corresponds to a subjective impairment grade 4.5* (the threshold of visibility). Taking another accepted figure of approximately 6 dB change per grade, coupled with the findings from various published literature[2,3,4,5] and other unpublished committee papers, led to establishing limits of 5%, 10%, and 20%; these being likely to give subjective picture impairments of grade 4.5, 3.5 and 2.5 respectively, as averages for the range of delay values under consideration. This was subsequently verified by

* The CCIR 5-grade impairment scale:

5 Imperceptible
4 Perceptible but not annoying
3 Slightly annoying
2 Annoying
1 Very annoying

a limited quantity of subjective gradings vs. objective measurements obtained during the field survey work (see Fig. 2).

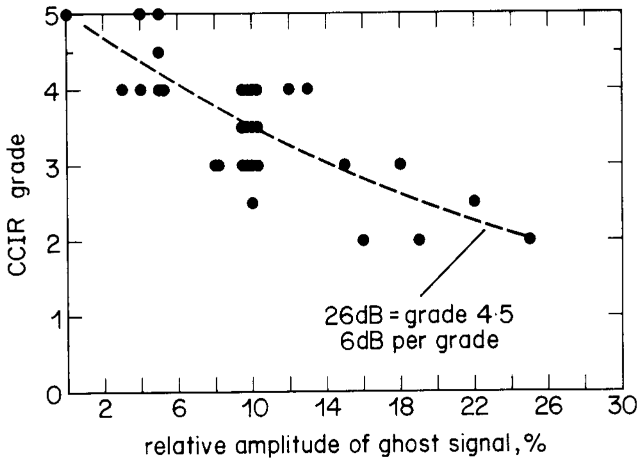


Fig. 2 - Relationship between objective measurements and subjective grades for single ghost in delay range 1.0 to 3.0 μs.

To the north of the tower, the angular separation between the wanted and unwanted signals is less than 15 degrees, and the two signals could be assumed equally affected by the relatively constant receiving antenna gain across this arc. Fortuitously, the delay was in the range 1.5 μs to 3.0 μs, which meant that the delayed pulse appeared in the area of black level between the main pulse and the 10T augmented pulse. The delayed pulse appears in various forms according to the relative carrier phase of the delayed signal, as shown in Fig. 3. For instrumental reasons, all objective measurements were made on Channel 33 (BBC-2), but at each location the four channels were compared subjectively, to verify that there were no untoward differences between channels. Before each measurement, the vehicle was shunted in an east-west direction to obtain a positive echo. A typical maximum shunt distance of about 3 m, for one complete cycle of phase change, had been computed and tabulated for each 1 km grid square in the survey area, together with the expected time delay between the main and echo pulse. In all cases, the measured delay was within 0.25 μs of the predicted value, which confirmed the source of the reflection as Canary Wharf tower.

3.1 Measurement of affected area north of the tower

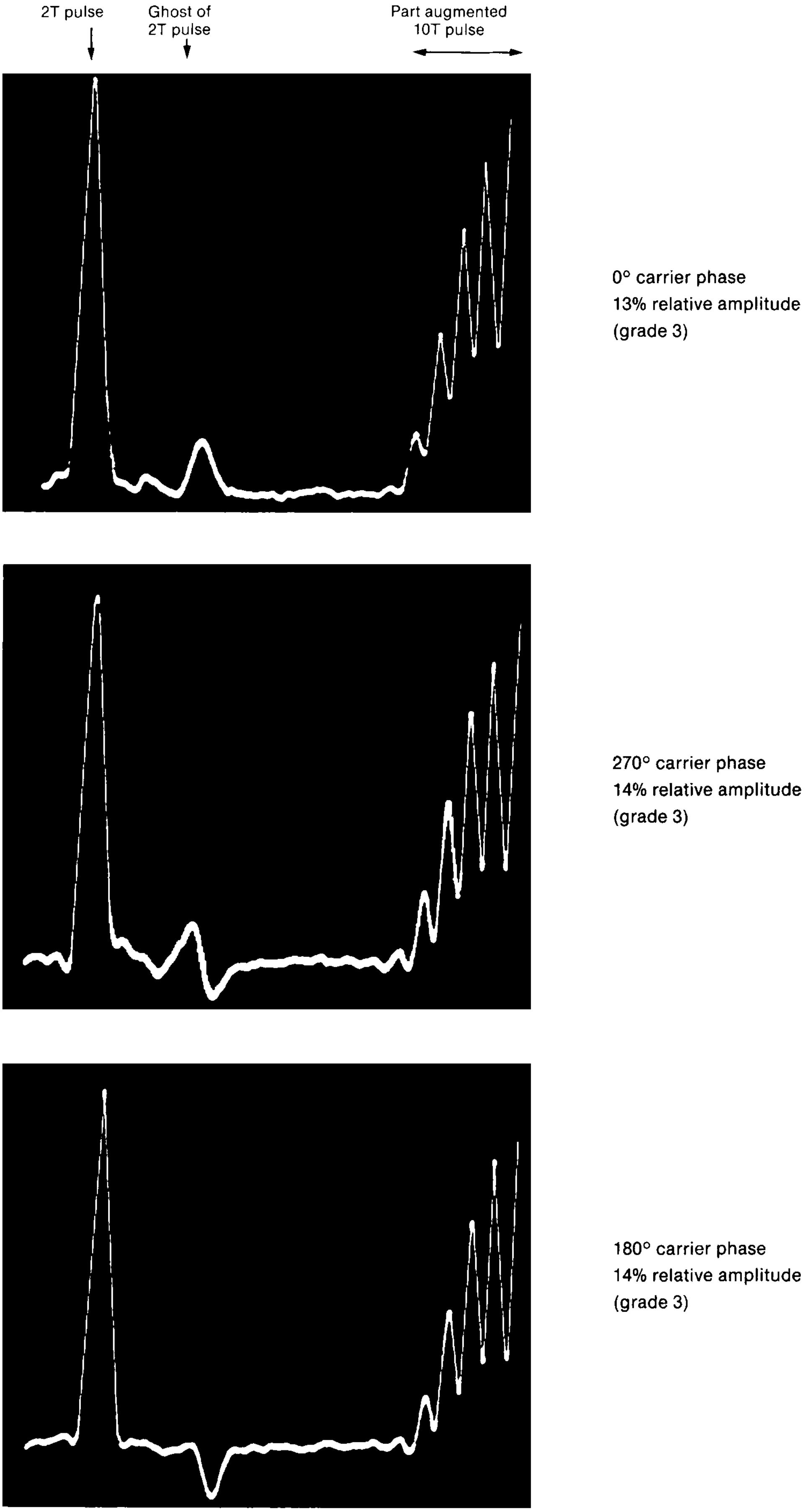
The measurement technique was to traverse a number of nominal east-west routes across the expected path of the reflection beam, using suitable roads at various distances to the north of the tower. Along each route, measurements were made at approximately 100 m intervals, each set of measurements effectively giving a profile of the beam field strength, relative to the main signal at the particular distance to the north. It was then possible to determine, for each traverse, points indicating the east and west boundaries of areas affected by ghosts that were greater than particular relative levels. By taking sufficient traverses at different distances to the north, it became possible to draw contours of the areas enclosed by three chosen levels of reflection. These chosen objectively measured levels, of 5%, 10% and 20%, are considered to be representative of impairment grades 4, 3, and 2 respectively, as discussed earlier. The resulting contour map appears as Fig. 4.

It is interesting to note that the relative amplitude of the ghost signal, to the direct signal at the centre of the beam, does not vary significantly with distance to the north. This verifies that the ghost signal comes from a point at the same distance from the receiver as the direct signal, i.e. from the image of Crystal Palace in the west face of the tower. This in turn shows that the tower is behaving as a reflector and not a re-radiator. If the latter were the case, a relative ghost amplitude of 20% at 25 km north of the tower would equate to 43% at 5 km, which was clearly not the case.

A population count for the three areas, based upon 1971 census information, showed that the number of people enclosed within each contour was as follows:

Ghost image		**Population**
⩾ 5%	(at or below CCIR grade 4.5)	156.000
⩾ 10%	(at or below CCIR grade 3.5)	98,000
⩾ 20%	(at or below CCIR grade 2)	36,000

Within any of these categories at any one time and for any one channel being watched, half of the households are likely to have a picture up to one grade better than suggested. This is because, statistically, the relative phase between the main and reflected carriers can be about 90 degrees or 270 degrees. Such phase orientations remove the low video frequencies, so that only high frequency edge information remains in the delayed image. It is unlikely that adjusting antenna mounting positions (in an east-west direction), for an optimum carrier phasing, would give households much benefit; the path length differences at any reception point are not likely to be stable enough. In any event, such adjustments would only apply to a single channel. At any particular time, therefore, it must be assumed that the whole population in an area has the poorer grading on two of the four available programme channels.



0° carrier phase
13% relative amplitude
(grade 3)

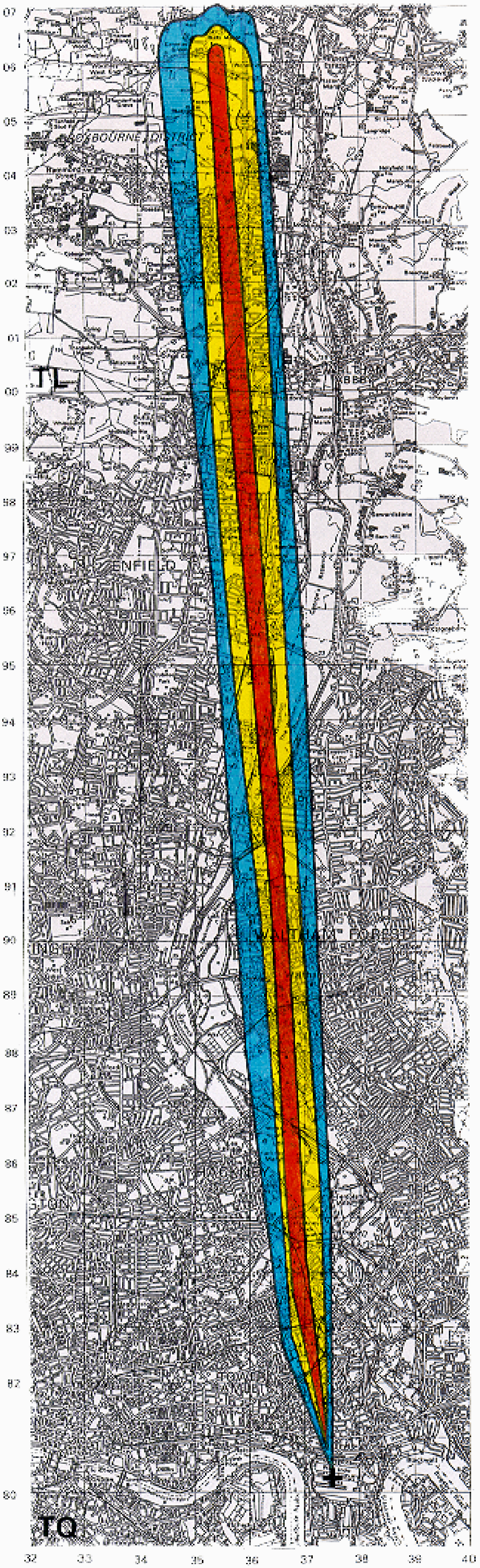
270° carrier phase
14% relative amplitude
(grade 3)

180° carrier phase
14% relative amplitude
(grade 3)

Fig. 3 - Appearance of delayed pulse at different carrier phase relationships.

ISSUED BY BBC RESEARCH DEPARTMENT TADWORTH SURREY   DATE: APRIL 1991
SERVICE PLANNING SECTION

K203551A3



Map key:

+ Location of Canary Wharf Tower

Delayed image

A B C B A

A: 5% - 10% (CCIR Grade 4)
B: 10% - 20% (CCIR Grade 3)
C: >20% (CCIR Grade 2)

Fig. 4 - Areas affected by ghost images at various relative amplitudes from the Canary Wharf tower in London's Docklands.

Licence No. AL 550299
Reproduced from the Ordnance Survey's
1:50,000 (scale) map of 1985 (year)
with the permission of the
Controller of Her Majesty's Stationery Office,
"Crown Copyright Reserved"

3.2 Building reflectance

Fig. 5 shows a measured profile of the ghost signal amplitude, relative to the main signal, for an east-west path across the beam, at approximately 18.5 km north of the tower. It is obvious that there is considerable dispersion, because the beam width covers about 1 km compared with the basic optics prediction of 30 m. Integrating the energy (i.e. the square of the relative ghost signal amplitude) across the width of the beam, shows it to be equivalent to a relative ghost amplitude of 83% across an ideal 30 m wide rectangular profile beam. This rather crude analysis suggests that the reflectance of the tower might be as high as 80%, with a collimated incident beam becoming dispersed over a horizontal angle of 3 degrees after reflection.

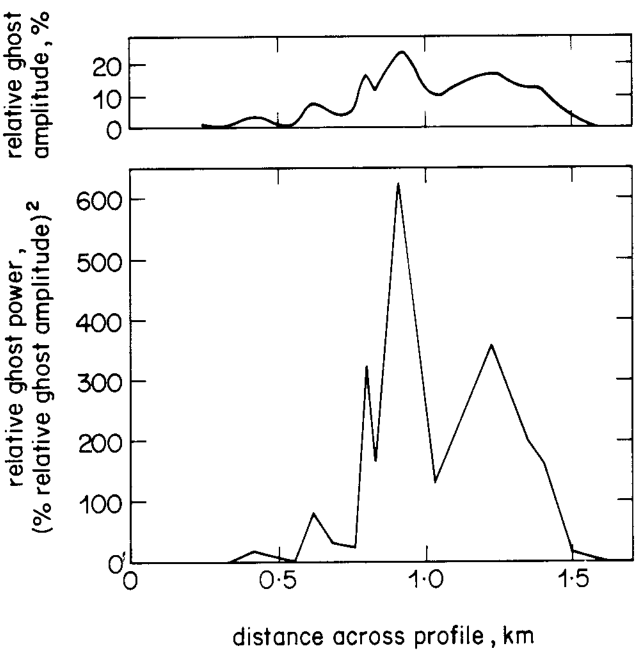
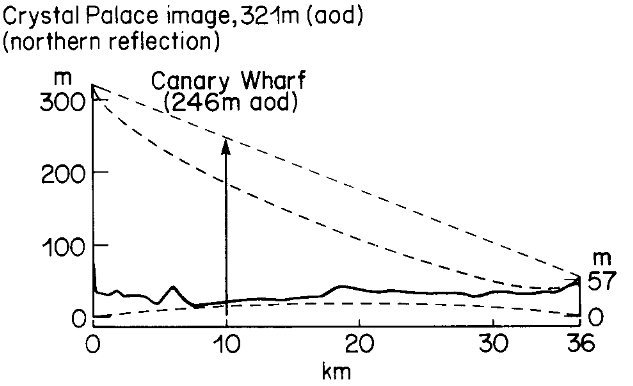


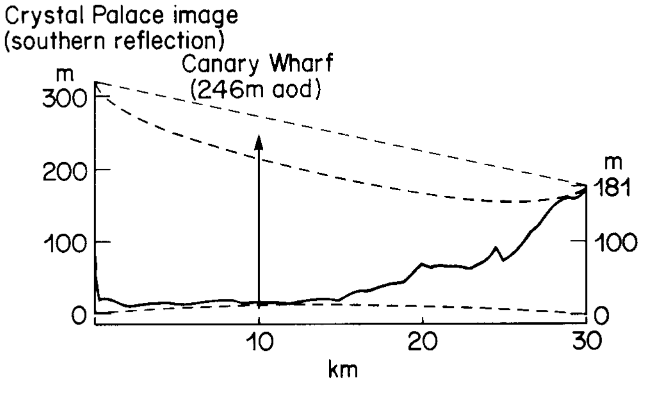
Fig. 5 - Profiles across the reflected beam of relative ghost signal amplitude and relative ghost signal power.

3.3 Reflections in the vertical plane

In order to make some prediction for the vertical plane, a terrain profile can be produced from the image of Crystal Palace, as seen behind the tower, towards the north, on the bearing as previously derived and shown in Fig. 1(a). This terrain profile appears as Fig. 6(a); a similar diagram for the southern beam appears as Fig. 6(b). The assumption is, that the angle of declination at which a reflected ray leaves the building, will be identical to the angle formed at the point where the ray from Crystal Palace strikes the building. For any given point along the reflection path, a line can be drawn to the Crystal Palace (image) antenna; this will intersect the tower at the height where the reflection for that point would be expected to be centred. This method of analysis was used to predict the furthest point to the north at which the ghost signal would be found. By prediction, a reflection point at the very top of the tower would produce a ghost at a distance of 24 km to the north of the tower, at half the previously sustained amplitude. Measurements showed that the relative amplitude of the ghost signal went below 5% between 26 km and 27 km north of the tower. It is clear that the deduced 3 degree dispersion on reflection, found in the horizontal plane, does not apply vertically; if it did, the reflected signal beam would extend to the radio horizon because the angle of declination from Crystal Palace to Canary Wharf is less than 0.5 degrees. This absence of any observable dispersion in the vertical plane, coupled with a significant amount in the horizontal plane, is obviously a function of the considerable height of the tower compared with its effective width as seen from the target area. The relatively small width is readily apparent from Fig. 7(a) which shows, in diagrammatic form, the west face of the tower as seen looking back down the reflected beam path. The superimposed circles show the positions and sizes of the first Fresnel zone at the tower for reception points at various distances to the

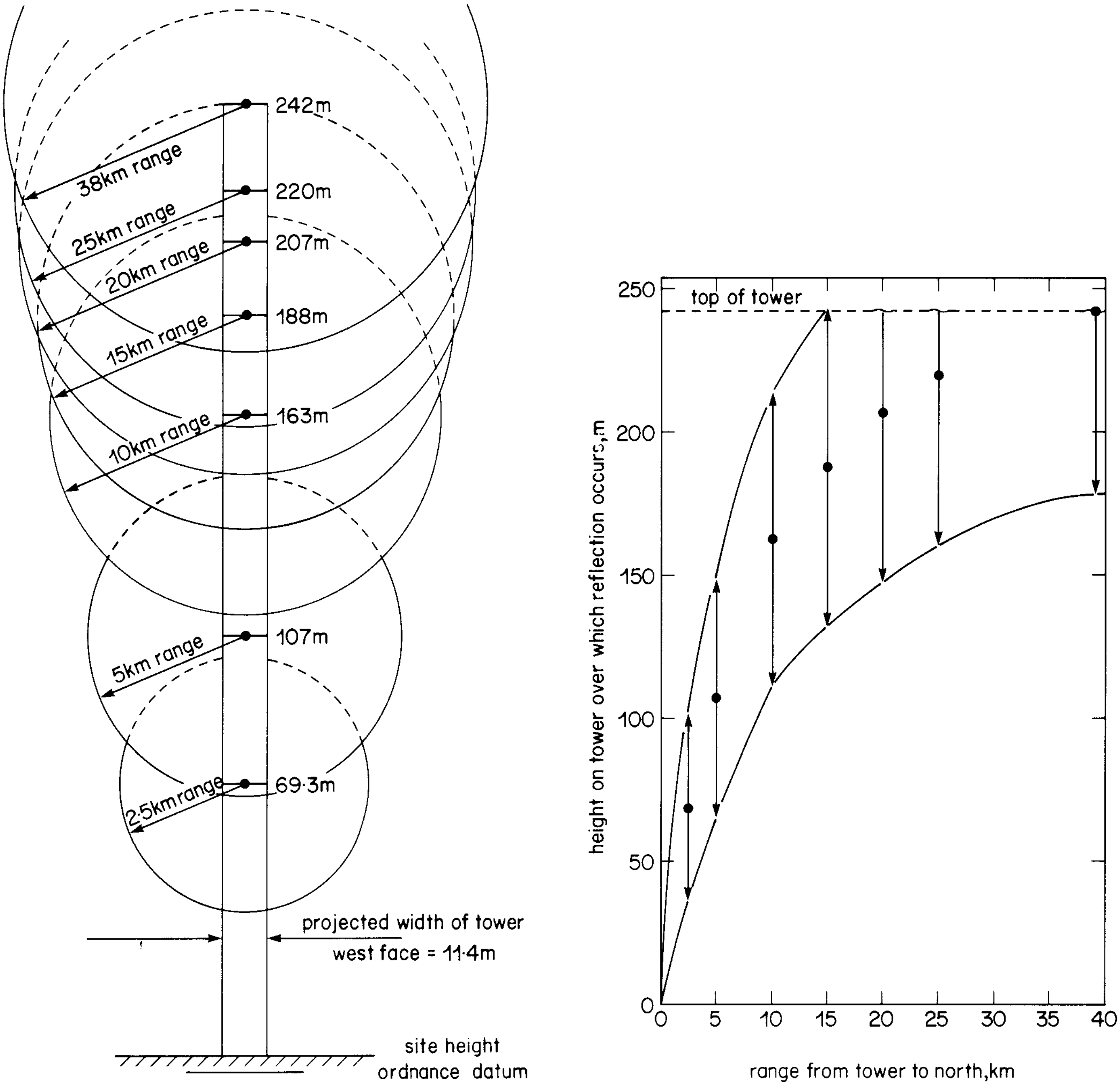


(a) Northern reflection.



(b) Southern reflection.

Fig. 6 - Terrain profile along the reflection beam from the position of the image of the Crystal Palace transmitter as seen via the Canary Wharf tower.



(a) Superimposed on a projection of the west face of the tower as seen from the receiving point.

(b) Graphical presentation of Fresnel zone height range versus receiving distance.

Fig. 7 - First Fresnel zones for various distances of receiving point from tower.

north. It can be assumed that for any reception point along the beam, the area of tower, enclosed by the first Fresnel zone for that reception distance, is the area causing the problem at that distance. Fig. 7(b) is an alternative presentation of the same information, which shows more clearly that, for most of the affected area, it is the upper part of the tower which causes the problem.

3.4 Southern reflection

At a point on the southerly reflection beam, due east of the Crystal Palace transmitter, the main and reflected signals approach on bearings about 100 degrees apart. Antenna directivity should significantly reduce the ghost amplitude, although problems could be experienced with a set-top antenna. There is also a path difference of up to 20 km between the main and reflected signals which further reduces the relative strength and, incidentally, makes the delay just under one television line period; hence, any delayed image would appear as a pre- rather than a post-echo. Only by deliberately misaligning the antenna at test points close to the southern beam, was it possible to locate this ghost and thereby confirm the existence of a reflected beam on the predicted bearing. There was no evidence of a reduced amount of dispersion to the south compared with the north. It is also suspected that the field strength of this beam may be less than would have been expected, if based upon findings made to the north. If confirmed, the possible reasons for this would require further investigation.

Further south, the path difference and antenna directivity advantages become less pronounced. But the declination of the reflected beam, coupled with the rising ground to the south, mean that the reflected signal should not exist beyond 17 km south of the tower. At this point, the two signals are still 27.6 degrees apart, giving a minimum antenna discrimination of 3.2 dB. It has not yet been possible to find any point to the south where there is a significant ghost impairment when using a properly aligned log-periodic receiving antenna.

4. POSSIBLE CURES FOR THE PROBLEM TO THE NORTH

Possible cures for the severe problem of ghost images from Canary Wharf, towards the north, fall into three main areas: prevention at the source, the use of discrimination at the receiving antenna and the provision of one or more additional transmitters.

4.1 Prevention at source

There is, in practice, no way to eradicate reflections completely from any structure. However, anything which tends to 'break up' the surface of a building will make a significant contribution to reducing the specular reflections of a smooth surface. Brick, concrete, etc. are sufficiently rough to attenuate reflected signals by dispersion. The effect of these is dramatically to improve the ratio of wanted to unwanted signals arriving at the receiving antenna. Ghosting may still occur, but usually only in areas where the direct signal itself is considerably attenuated by other buildings and/or terrain. Conversely, metal cladding on buildings or large areas of metallised windows, will tend to give rise to specular reflections, whose magnitudes almost equal that of the incident signal. For the particular problem of Canary Wharf, the following are possible hypothetical remedies:

(a) Apply some absorbent coating to as much of the west face of the building as possible, to cause more of the incident energy to be absorbed, thereby reducing the strength of the reflection. Various coatings are available, including a 6 mm ferrite tile, which will absorb wavelengths up to 3 m, and a paint, which works at SHF; it is probable that a 1 mm coating could be found or developed to provide sufficient absorption at UHF. A coating is likely to be dark in colour and, of course, cannot be applied to the windows. It may be possible to contrive a coating which causes the reflection from the walls to be in antiphase to that from the windows.

(b) Modify the coarse texture of the west face of the building, to increase the dispersion of the reflected beam so that the energy in any particular area is insufficient to cause a problem.

(c) Modify the west face of the building, to re-direct the reflections into the sky by tilting the steel cladding plates slightly upward.

(d) Use baffles to re-direct the incident energy, which would otherwise strike the west face of the building. This could give rise to mechanical problems such as adverse wind loading.

(e) Erect another equally tall but more absorbent building directly across the path of the incident or reflected beams.

All of these hypothetical solutions would be expensive to implement, due to the sheer size of the building, and with success not guaranteed. It would be advisable to undertake a test of any such proposals using a scale model. Microwave frequencies at 12 GHz could be used for the test (giving a convenient scale factor of 20:1). A panel representing the west face of the present building would then need to be 12 m high by 2.5 m wide.

4.2 Receiving antenna discrimination

Preventing or reducing the effect of reflections at the receiving antenna may be easier at some locations than others. As has already been intimated, where the angle of wanted and unwanted signals exceeds 30 degrees, the receiving antenna, being directional, provides some discrimination against ghosting. The typical Yagi type of receiving antenna, as used domestically, has little or no discrimination at 20 degrees 'off-bore-sight'; at 60 degrees or more, it rises to about 15 dB (17.8% in voltage terms). A good log-periodic type of antenna has little or no discrimination at 30 degrees, rising to about 25 dB (5.6% in voltage terms). Unfortunately, the reflection towards the north, from the western face at Canary Wharf, arrives at an angle of only 10-15 degrees to the antenna, relative to the main signal; the conventional antennas, described above, cannot reject such a narrowly displaced signal (reflection).

It is possible to cancel the effect of a near on-axis interfering signal at important reception sites, such as relay transmitters, by using two antennas spaced apart (horizontally) by about 1 m. The exact separation can be calculated from the relative bearing of the interfering signal and the mean wavelength for the channels concerned. The outputs of the two antennas are added in phase using a simple 3 dB coupler. In practice, a separation based on mean wavelength should give adequate rejection of the interference across the 10 channel spread of a standard transmission group. The disavantages of this solution, for domestic use, are that it would be expensive to implement and perhaps difficult to mount, due to the relatively large spacing needed.

The reflection from the southern face of the offending building at Canary Wharf, is far less of a problem, due to the relative bearing being generally greater than 30 degrees. Additional discrimination might be achieved by either changing to a log-periodic antenna, and/or mounting the receiving antenna on the side of the domestic residence 'away' from Canary Wharf so that the roof 'cuts off' the interfering signals.

4.3 A new transmitter

Providing an alternative television service, with a new transmitter for the affected area, is perfectly feasible in theory. Unfortunately, the UHF spectrum is now so crowded in the south-east of England that no further channels can be found for a transmitter of the power that would be required for a problem area as large as that produced by the reflections from Canary Wharf. It was only just possible to find four usable channels for the proposed relay station at Poplar to cover the Canary Wharf shadow area. The number of viewers able to change their antennas and use the existing relay transmitters (including the one at Poplar), is estimated to be less than 10% of those affected.

4.4 Cancellation at receiver

There have been various reports in the technical press, concerning electronic ghost cancelling systems for television signals; in particular, one paper reported successful field trials in the USA of a prototype television set which included such a system[6]. A ghost-cancelling unit could, in principle, be inserted into the antenna lead of an existing receiver. As an 'add-on' box, however, such a circuit would need to contain a tuner, an automatic correction circuit operating at video frequencies and a remodulator, together with the associated power supply and case. It is understood that devices of similar complexity (conditional access descrambler boxes) have been produced in Japan, at a factory gate price of £60. It has not so far been possible to obtain any further details of how an aerial-connected ghost cancelling unit would be used, particularly with regard to operation on four channels, and with the possible need for remotely controlled tuning, or when used in conjunction with a video recorder.

Due to their relatively low speed in obtaining the optimum correction condition, the setting achieved for each channel should be saved, so that it is quickly recovered for any channel selected. Another factor to consider, is that severe wind conditions may deflect the transmitting mast or the reflecting building, causing the relative phase of the ghost signal to vary. If the natural frequency of oscillation is too high, the correction circuit may not be able to follow such changes.

It is thought unlikely that an add-on device, which combines successful ghost cancellation, low cost and convenient tuning arrangements, will become commercially deliverable in the immediate future. On the other hand, it is quite likely that ghost cancelling circuits will be included as an integral part of at least some models of new television receivers and video recorders within the next ten years. If all television receivers and video recorders were to include ghost cancelling circuits, problems such as that created by the Canary Wharf tower could cease to exist.

5. CONCLUSIONS

The extent of the area affected by delayed image interference from the large tower, at Canary Wharf in London Docklands, has been surveyed in some detail and it is confirmed that in excess of 100,000 people have had their television pictures affected to some degree. Some understanding of the mechanism of the reflection has been gained; possible remedies have been suggested, although all would require further proving work and would be very expensive to implement. Thus, to date no practical cure to the problem has been found.

Further work is required to the south of London, to confirm that the problem there is less severe than calculations based on the northern findings would suggest, and to explain the reason if this is found to be so. The results could yield further information leading to ways of avoiding problems from future developments involving large structures.

Nevertheless, the experience gained in this particular case study, and with some other new building developments, indicate that the construction of large, tall buildings can create serious and intractable problems for television broadcast reception by the general public. The potential for such environmental effects has been brought to the attention of the Television Planning Group of the DTI's Radiocommunications Agency. Local planning authorities also need to be made aware of the possible problems.

6. REFERENCES

1. CCIR, 1974-1986. Report 624-4: Characteristics of television systems. CCIR Study Group 11. Recommendations and Reports of the CCIR 1990 Annex to Volume XI-I, pp 1-33.

2. CCIR, 1970-1990. Report 478-2: Ghost images in television. CCIR Study Group 11. Recommendations and Reports of the CCIR 1990 Annex to Volume XI-I, pp 476-477.

3. CORBETT, J.M. et al., 1974. Subjective quality of television pictures impaired by short-delay echo. *Proc. IEE*, **121**, No. 7.

4. LESSMAN, A.M., 1972. The subjective effects of echoes in 525-line monochrome and NTSC color television and the resulting echo time weighting. *J. SMPTE*, **81**.

5. ALLNATT, J.W. et al., 1965. Subjective quality of television pictures impaired by long-delayed echo. *Proc. IEE*, **112**, No. 3.

6. TAWIL, V. and CLAUDY, L., 1990. Field testing of a ghost cancelling system for NTSC Television Broadcasting. *IEE Transactions on Broadcasting*, **36**, No. 4.